

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
1 November 2001 (01.11.2001)

PCT

(10) International Publication Number
WO 01/82355 A2

(51) International Patent Classification⁷: H01L 21/306, 21/00

(81) Designated States (national): AL, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KH, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(21) International Application Number: PCT/US01/13002

(22) International Filing Date: 23 April 2001 (23.04.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data: 60/199,354 25 April 2000 (25.04.2000) US

(71) Applicant (for all designated States except US): TOKYO ELECTRON LIMITED [JP/JP]; TBS Broadcast Center, 3-6 Akasaka 5-chome, Minato-ku, Tokyo 107 (JP).

(72) Inventor; and

(75) Inventor/Applicant (for US only): LIU, Lianjun [US/US]; 100 W. Napal Place #232, Chandler, AZ 85224 (US).

(74) Agents: LAZAR, Dale, S. et al.; Pillsbury Winthrop LLP, 1100 New York Avenue, N.W. Washington, DC 20005 (US).

(84) Designated States (regional): ARIPO patent (GII, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

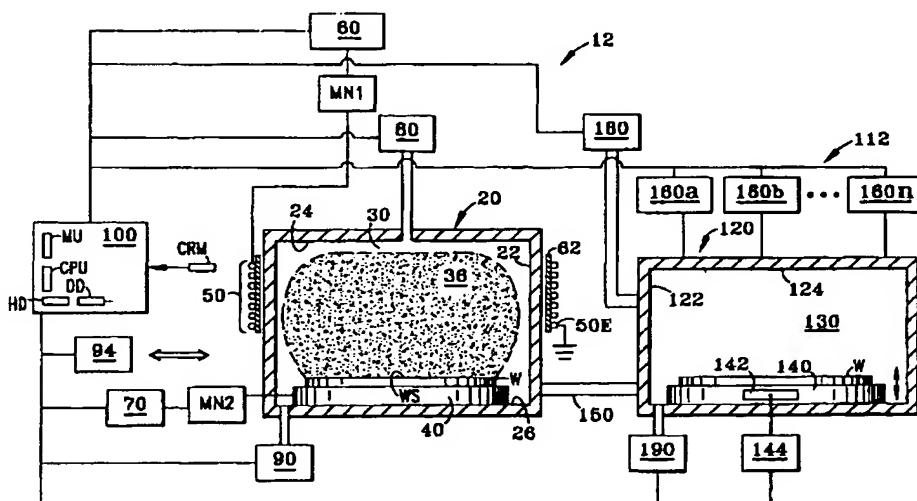
Published:
— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND APPARATUS FOR PLASMA CLEANING OF WORKPIECES



WO 01/82355 A2



(57) Abstract: A method and apparatus for plasma cleaning a workpiece (W) in a plasma-cleaning chamber (20) having an interior region (30). The method comprises the steps of first, loading the workpiece into the plasma-cleaning chamber interior region. The next step is pumping down the plasma-cleaning chamber interior region down to a pre-determined pressure, with hydrogen as the ambient gas. The next step is forming from the hydrogen gas a plasma (36) having an ion density in the range between 10^{10} and 10^{13} cm^{-3} and an ion energy lower than 30 eV. The last step is exposing the workpiece to the plasma for a predetermined time. The apparatus of the present invention preferably includes first and second vacuum processing chambers (20 and 120), wherein the first chamber performs the plasma cleaning of the workpiece according to the method of the invention, and the second chamber performs an additional process step, e.g., depositing a metal.

METHOD AND APPARATUS FOR PLASMA CLEANING OF WORKPIECES

This application claims the benefit of U.S. Provisional Application No.
5 60/199,354 filed April 25, 2000.

BACKGROUND OF THE INVENTION

The present invention relates to the preparation of workpieces, and in particular relates to the cleaning of workpiece surfaces using a hydrogen-based plasma.

10 A fundamental step in the manufacturing of semiconductor devices, such as integrated circuits (ICs), is the process of forming electrical interconnections, or "contacts." The formation of a low resistance contact involves the steps of providing a semiconductor workpiece, such as a silicon wafer, cleaning the surface of the workpiece, selectively depositing a metal, such as titanium, on the surface, and thermally annealing the metal. Where the metal is titanium, the annealing process causes the formation of titanium silicide, which consumes some 15 of the underlying silicon.

20 Unfortunately, as minimum circuit dimensions decrease, the use of metals for forming the electrical contacts becomes problematic. This is primarily because the resistivity of the metal-silicon (e.g., titanium silicide) contact increases dramatically when the size of contact (i.e., the "line width") is one micron or less. Compounding the problem, as line widths diminish below one micron, device 25 junction depths decrease to just a few hundred angstroms. Since the formation of silicides consumes some of the underlying silicon, a reduction in the junction depth to a few hundred angstroms means that the integrity of the junction is at risk.

30 Use of the metal cobalt has been proposed as a solution to the above-described problems associated with titanium-based contacts, and is used in sub 0.25 micron manufacturing processes. However, the use of cobalt in forming contacts introduces additional problems. For example, cobalt does not react with silicon oxides or any of the other likely surface contaminants, such as water and C-F

polymers. Consequently, the surface of the wafer prior to cobalt deposition must be far cleaner than what is necessary for other metal-silicon contacts, such as titanium silicide.

- 5 There are two techniques currently used in semiconductor manufacturing to clean workpiece surfaces prior to forming contacts using cobalt. One method is to clean the wafer in a variety of chemical solutions, including a final step of cleaning the wafer with a hydrofluoric (HF) dip. Though this approach is effective for many cleaning processes (especially those involving 0.5 micron technology and higher),
- 10 HF is not as sufficiently reliable for sub 0.25 micron technology. Furthermore, this chemical poses significant health risks to operators and technicians. Moreover, workpieces to be processed must be transported from the HF dip tank to the deposition reactor. In this transportation step the workpieces are exposed to air, which oxidizes the exposed surface, thereby degrading device performance
- 15 and reducing process tolerances.

The second workpiece cleaning surface method used prior to cobalt deposition involves sputtering the workpiece surface with argon ions. To be effective, the energy of the ions must be reasonably high. Unfortunately, use of such high-energy ions is problematic. For example, sputtering at such high energies can result in argon being incorporated into the silicon. Such ions can result in the generation of crystal defects as deep as several hundred angstroms. Other problems include erosion of the silicon itself, re-deposition of the sputtered materials, and the penetration of surface contaminants into the silicon.

- 25 The use of hydrogen plasma has been proposed as a method for cleaning surfaces. Since the chemical byproducts of hydrogen plasma are essentially gaseous, the cleaning process should be very effective. However, when the use of hydrogen plasma to clean wafers was studied, numerous problems emerged. For example,
- 30 when using a parallel plate reactive ion etch (RIE) system, severe silicon erosion and the diffusion of hydrogen into the silicon resulted from the high ion energy generated in the source plasma. When a microwave-excited downstream plasma was used, the removal rate of the native oxide and other contaminants was significantly reduced due to the low energy of the hydrogen radicals and the

reduction of radical concentration during the transportation from the source to the wafer surface.

BRIEF SUMMARY OF THE INVENTION

5 The present invention relates to the preparation of workpieces, and in particular relates to the cleaning of workpiece surfaces using a hydrogen-based plasma.

A first aspect of the invention is a method of plasma cleaning a workpiece in a plasma-cleaning chamber having an interior region. The method comprises the 10 steps of first, loading the workpiece into the plasma cleaning chamber interior region. The next step is pumping the plasma cleaning chamber interior region down to a pre-determined pressure, with hydrogen as the ambient gas. The next step is forming from the hydrogen gas a plasma having an ion density in the range of 10^{10} to 10^{13} cm⁻³ and preferably greater than 10^{12} cm⁻³, and an ion energy lower 15 than 30 eV and preferably in the range from 10 to 15 eV. The last step is exposing the workpiece to the plasma for a predetermined time.

A second aspect of the invention is the method as described above, further including the steps, after the wafer is cleaned, of transferring the workpiece from 20 the plasma cleaning chamber to a processing chamber, and then performing a process step to the workpiece. This process step may be, for example, depositing a metal.

A third aspect of the invention is an integrated workpiece processing apparatus for 25 plasma cleaning a workpiece and then processing the workpiece. The apparatus comprises a first vacuum processing chamber adapted to plasma clean a workpiece with a plasma having a high ion density, low ion energy and low plasma potential. The first vacuum processing chamber includes a workpiece support fitted therein. The apparatus also includes a second vacuum processing 30 chamber adapted to perform a process selected from the group consisting of CVD, PVD, sputtering, and etching of a workpiece. The second processing chamber is also fitted with a workpiece support. Further included in the apparatus is a vacuum transfer chamber connecting the first and second chambers. The transfer chamber is sized so that a workpiece may pass between the chambers. The

purpose of the transfer chamber is to prevent the workpiece from being exposed to contaminants (i.e. oxygen or water vapor, etc.) after it has been cleaned in the first vacuum processing chamber.

5 BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. 1 is a schematic diagram of the plasma-cleaning system of the present invention, shown as used in combination with a process chamber used to process the workpiece after it is cleaned in the plasma-cleaning chamber; and

10 FIG. 2 is a close-up perspective view of the plasma-cleaning chamber of the system shown in FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

15 The present invention relates to the preparation of workpieces, and in particular relates to the cleaning of workpiece surfaces using a hydrogen-based plasma. The present invention is particularly useful in preparing a workpiece in which low-resistivity metal silicide contacts are to be formed in the process of fabricating semiconductor devices in a silicon workpiece (wafer).

20 With reference now to FIG. 1, there is shown a plasma-cleaning system 12 in the form of an ESRF plasma reactor (though other reactors, such as a neutral-loop plasma (NLP) reactor, an ultra-high frequency (UHF) plasma reactor, and the like could also be used). System 12 comprises a plasma-cleaning chamber 20 as a vacuum processing chamber adapted to perform plasma cleaning of a workpiece 25 W, such as a silicon wafer. Workpiece W has an upper surface WS. Chamber 20 has sidewalls 22, an upper wall 24 and a lower wall 26 that enclose an interior region 30 capable of supporting a hydrogen plasma 36. The latter has a high ion density and low ion energy, arising from a low voltage (potential). These plasma properties minimize ion penetration into workpiece surface WS and are a key 30 aspect of the present invention. Chamber 20 includes within region 30 a workpiece support 40 arranged adjacent lower wall 26 for supporting workpiece W while the workpiece is processed in chamber 20. The workpiece support 40 preferably includes a lifting member (not shown) for vertical translation in order to position workpiece support 40 for workpiece exchange as well as position the

workpiece at an optimal position relative to the plasma for process. The optimal position may be one that achieves an acceptable rate for the cleaning process and spatial uniformity of the cleaning process.

- 5 With reference to FIG. 2, in a preferred embodiment, chamber 20 of plasma-cleaning system 12 includes an inductive coil 50 wrapped around chamber sidewalls 22 so as to surround interior region 30. Inductive coil 50 may be a helical resonator (i.e. a quarter-wave or half-wave resonator), wherein one coil end 50E (shown in FIG. 1) is grounded, and the opposite coil end is open. Coil 50
- 10 is electrically connected to a chamber RF power supply 60 through a match network MN1. For a helical resonator, match network MN1 will be connected to a tap location generally near grounded end 50E. The latter is used to maximize RF power transfer to plasma 36.
- 15 Between inductive coil 50 and chamber walls 22 is a grounded electrostatic shield 62 (also referred to as an E-shield or Faraday shield) comprising an electrically grounded, conductive sheet with slots 62S each having a bottom 62B and a top 62T. Slots 62S are aligned parallel with the axis of revolution A of chamber 20 and are typically equally spaced. Slots 62S may have a width, for example, of
- 20 between 2mm-6mm. The total area covered by all slots 62S should preferably fall into the range of 0.2 to 5% of the total area of shield 62. E-shield 62 minimizes capacitive coupling between coils 50 and plasma 36 by limiting the area of slots 62S through which the electromagnetic field from the coils can couple to the plasma.
- 25 With reference again to FIG. 1, system 12 also includes a workpiece support RF power supply 70 electronically connected to workpiece support 40 through a match network MN2, to supply an electrical bias to the workpiece.
- 30 Plasma-cleaning system 12 further includes gas supply system 80 in pneumatic communication with plasma-cleaning chamber 20 via a gas conduit 82. Gas supply system 80 includes a source of hydrogen gas 86 used to create hydrogen plasma 36. Preferably only hydrogen gas is used for the cleaning process. However, other gases, in particular inert gases, may be used as a dilution gas. For

example, helium may be used as a dilution gas. However, due to its high ionization energy, it can raise the "tail" of the electron energy distribution function, which can be a disadvantage to the process. Moreover, argon could be used as the dilution gas. However, due to its mass, it has the disadvantage of

5 increasing the ion bombardment of the sensitive contact surface. Gas supply system 80 also regulates the flow of hydrogen gas to chamber interior region 30. Gas supply system 80 also connects appropriate gasses to a second processing chamber, as discussed below.

10 Plasma cleaning system 12 also includes a vacuum pump system 90 pneumatically connected to chamber 20 for evacuating interior region 30 to at least approximately 1-100 mTorr. Further included in plasma cleaning system 12 is a workpiece handling and robotic system 94 that transports workpieces W to and from workpiece support 40.

15 RF power supplies 60 and 70, gas supply system 80, vacuum pump system 90 and workpiece handling and robotic system 94 are all electronically connected to and controlled by a main control system 100.

20 In a preferred embodiment, main control system 100 is a computer having a memory unit MU having both random-access memory (RAM) and read-only memory (ROM), a central processing unit CPU (e.g., PENTIUM™ processor from Intel Corporation), and a hard disk HD, all electronically connected. Hard disk HD serves as a secondary computer-readable storage medium, and may be,

25 for example, a hard disk drive for storing information corresponding to instructions for control system 184 to carry out the present invention, as described below. Control system 100 also preferably includes a disk drive DD, electronically connected to hard disk HD, memory unit MU and central processing unit CPU, wherein the disk drive is capable of accepting and reading (and even

30 writing to) a computer-readable medium CRM, such as a floppy disk or compact disk (CD), on which is stored information corresponding to instructions for control system 100 to carry out the present invention. It is also preferable that main control system 100 have data acquisition and control capability. A preferred

control system 100 is a computer, such as a DELL PRECISION WORKSTATION 610TM, available from Dell Corporation, Dallas, Texas.

With continuing reference to FIG. 1, in a preferred embodiment of the present invention, plasma-cleaning system 12 is in operable communication with a workpiece processing system 112 for further processing workpiece W after it is cleaned in the plasma-cleaning system. Workpiece processing system 112 includes a process chamber 120 as a second vacuum processing chamber adapted to perform a desired process, such as chemical vapor deposition (CVD), physical vapor deposition (PVD), etching, or sputtering, on workpiece W. Chamber 120 has sidewalls 122, an upper wall 124 and a lower wall 126 that enclose an interior region 130. Chamber 120 includes within region 130 a workpiece support 140 arranged adjacent lower wall 126 for supporting workpiece W while the workpiece is processed. Workpiece support 140 includes a heater 142 and heater power supply 144 electrically connected to the heater. Workpiece support 140 is preferably adjustable so that workpiece W can be positioned in different locations within interior region 130.

Workpiece processing system 112 further includes a second gas supply system 180 pneumatically connected to process chamber 120 via gas conduit 182. Alternatively, a gas supply system 80 could also be used to supply gas to chamber 120. Also included is a vacuum pump system 190 pneumatically connected to chamber 120 and capable of producing a vacuum of at least approximately 1-100 mTorr. Alternatively, vacuum pump system 90 could also be connected to chamber 120 and used to control the pressure in interior region 30.

Heater power supply 144, gas supply system 180, and vacuum pump system 190 are also electronically connected to and controlled by control system 100.

In the present preferred embodiment, systems 12 and 112 are interconnected via a vacuum transfer (or "load lock") chamber 150 through respective chamber sidewalls 22 and 122. In this preferred embodiment, workpiece handling and robotics system 94 also transports workpiece W between chambers 20 and 120, and also removes the workpiece from workpiece support 140 after processing in

chamber 120. This allows for transfer of workpiece W from chamber 20 to chamber 120 while in a contamination-free environment.

Also, control system 100 is shown in electronic communication with various 5 systems 160a, 160b,..160n which may be conventional individual power sources for individual segments of a segmented electrode (not shown).

In the above-described preferred embodiment, the combination of plasma-cleaning system 12 and workpiece processing system 112, along with the 10 accompanying elements, constitute an integrated workpiece processing apparatus. All of the individual components and systems of systems 12 and 112 can be constituted by known, commercially available components And systems or can be constructed on the basis of knowledge already possessed by those skilled in the art.

15

Method of Operation

With continuing reference to FIG. 1, control system 100 causes workpiece handling and robotics system 94 to load a workpiece onto workpiece support 40 in plasma-cleaning chamber 20. Control system 100 then sends an electronic signal 20 to vacuum system 90 to evacuate interior region 30 of plasma-cleaning chamber 20. Subsequently, control system 100 signals gas supply system 80 to introduce a controlled flow of a gas composed solely or predominantly of hydrogen, into interior region 30 of chamber 20 while sustaining the desired pressure inside the chamber. When chamber interior region 30 reaches a desired pressure, control 25 system 100 signals RF power supply 60 to energize the gas to form plasma 36 in interior region 30.

Preferably the gas used for the cleaning process is composed only of hydrogen. However, other gases, in particular inert gases, may be used as dilution gas, 30 provided that the gas composition does not introduce any unwanted chemical species in the cleaning process. For example, helium may be used as a dilution gas, although, due to its high ionization energy, it can raise the "tail" of the electron energy distribution function and this can be a disadvantage to the process. Moreover, argon could be used as the dilution gas, although, due to its mass, it has

the disadvantage of increasing the ion bombardment of the sensitive contact surface.

As mentioned above, plasma 36 is formed so as to have a high ion density (e.g., 5 from 10^{10} to 10^{13} ion/cm³, preferably of order 10^{12} ion/cm³), and low ion energy (e.g., less than 30 eV, preferably of order of 10 to 15 eV depending upon the RF bias power). This type of plasma has been found by the present inventors to be well-suited for cleaning substrates that have significant topography e.g., contacts, 10 of contaminants such as oxides, organic residues, etching polymers, heavy metal atoms and water molecules, etc.

In particular, plasma 36 cleans workpiece W in the manner described as follows. As mentioned above, a key aspect of the present invention is the low plasma potential resulting from the use of E-shield 62. This means that if no bias is 15 applied to workpiece W from workpiece RF power supply 70, the energy of the ions and the electrons in plasma 36 reaching the workpiece will be very low. Thus, in the case of no external applied bias from workpiece RF power supply 70, there is significantly reduced ionic bombardment of workpiece surface WS. Adjusting the bias applied to workpiece support 40 increases the kinetic energy of 20 ions arriving at substrate surface WS. In addition, varying the amount of RF power from RF power supply 60 alters the ion density in plasma 36, while maintaining the energy of the ions at substantially the same level (typically on the order of 5 to 30 eV depending upon the RF bias power). This allows for control over the anisotropic etch characteristics of plasma 36. Thus, plasma 36 can be 25 adjusted to have the right balance of "etching strength" (i.e., ion energy)—enough to clean workpiece surface WS without significantly etching into the surface—combined with the proper directionality (i.e., anisotropic etch, in a direction perpendicular to the workpiece surface).

30 The chemical and mechanical processes involved in the removal of contaminant material from the sensitive surfaces at the bottom of high aspect ratio contacts formed in workpiece W can be categorized as a plasma enhanced etch. In a preferred embodiment of the present invention, a hydrogen chemistry is employed to volatize a thin layer of contaminants subject to a shower of H⁺ and H₂⁺ ions.

The primary independent process parameters available for adjusting the process include the gas specie(s), gas flow rate, chamber gas pressure, RF source power, and RF bias power (or workpiece holder peak-to-peak voltage). The above independent process parameters are then adjusted to provide an ion density and 5 ion energy in the ranges provided above, wherein they are fine tuned to optimize the process. A preferred range of operating parameters for the cleaning process are 10 to 1000 sccm of hydrogen gas, preferably about 200 sccm, 1 to 500 mTorr chamber pressure, preferably 10 to 100 mTorr, 1 to 5 kW RF source power, preferably 3 kW at 50 mTorr, and 0 to 20 Volts (peak-to-peak RF bias on the 10 workpiece holder (or chuck). Typically, the RF frequency for both the inductive coil and the chuck bias would be, for example, 13.56 MHz.

Upon terminating the cleaning process, control system 100 sends an electronic signal to wafer handling and robotics system 94, which then acts in response to 15 the signal to remove workpiece W from workpiece support 40. At this point, workpiece W can be transported through vacuum transportation chamber 150 to wafer support 140 in processing chamber 120 via wafer handling and robotics system 94. In a preferred embodiment of the present invention, workpiece W is a semiconductor wafer having a patterned surface (e.g., contact 20 areas) that have been cleaned in plasma-cleaning chamber 20. Further, processing chamber 120 is preferably capable of depositing a metal layer to form low-resistance metal-silicide electrical connections (e.g., contacts) in the process of fabricating a semiconductor device. Any operation to be performed in process chamber 112 will be performed in a manner already known to those skilled in the 25 art.

Although the above-described plasma-cleaning system 12 has been described in connection with an ESRF plasma reactor, it will be understood that alternate systems, including a neutral loop plasma (a Faraday shield in the form of a coil 30 partially inside the reactor), or an ultra high frequency plasma, or an inductively coupled plasma (ICP) system capable of forming a high-density, low-potential plasma are also suitable for practicing the process of the present invention.

In fact, the many features and advantages of the present invention are apparent from the detailed specification and thus, it is intended by the appended claims to cover all such features and advantages of the described process which follow in the true spirit and scope of the invention. Further, since numerous modifications 5 and changes will readily occur to those of ordinary skill in the art, it is not desired to limit the invention to the exact construction and operation illustrated and described. Moreover, the process and apparatus of the present invention, like related apparatus and processes used in the semiconductor arts tend to be complex in nature and are often best practiced by empirically determining the appropriate 10 values of the operating parameters, or by conducting computer simulations to arrive at best design for a given application. Accordingly, all suitable modifications and equivalents should be considered as falling within the spirit and scope of the invention.

CLAIMS:

1. A method of plasma cleaning a workpiece in a plasma-cleaning chamber having an interior region, comprising the steps of:
 - 5 a) loading the workpiece into the chamber interior region;
 - b) pumping the chamber interior region down to a pre-determined pressure with an ambient gas containing hydrogen;
 - c) forming from said ambient gas a plasma having an ion density in the range of 10^{10} to 10^{13} cm⁻³, and an ion energy lower than 30 eV;

10 and

 - d) exposing the workpiece to said plasma for a predetermined time sufficient to clean the workpiece.
2. A method according to claim 1, further including the steps of:
 - 15 e) transferring the workpiece from the plasma-cleaning chamber to a processing chamber; and
 - f) performing a process on the workpiece in the processing chamber.
3. A method according to claim 2, wherein said process includes depositing metal.

20
4. A method according to claim 1, wherein the ion density is greater than 10^{12} cm⁻³ and the ion energy is between 10 eV and 15 eV in said forming step.

25
5. A method according to claim 1, wherein said step of forming a plasma comprises supplying RF power in a range between 1 kW and 5 kW to the chamber interior region.
- 30 6. A method according to claim 5, wherein the amount of RF power supplied to the plasma is 3 kW and the predetermined pressure is 50 mTorr.

7. A method according to claim 1, further comprising causing hydrogen gas to flow into the chamber interior region at a rate of between 10 and 1000 sccm.
- 5 8. A method according to claim 1, wherein the predetermined pressure is in the range of 1 to 500 mTorr.
9. A method according to claim 1, wherein said step of loading comprises placing the workpiece on a workpiece holder, and said method further 10 comprises applying an RF voltage having a peak-to-peak value not greater than 20V to the workpiece holder.
10. A method according to claim 1, wherein the ambient gas further contains at least one of helium and argon.
- 15 11. A method according to claim 1, wherein the ambient gas consists of hydrogen.
12. A method according to claim 2, wherein said transferring step includes a 20 step of transporting the workpiece through a contamination-free environment.
13. A method according to claim 2, wherein said processing chamber is one of a 25 sputtering chamber, a PVD chamber, a CVD chamber, and an etching chamber.
14. A method according to claim 1, wherein said plasma removes at least one material from the workpiece from the group of materials consisting of 30 oxide, water, organic residue, etching polymers, and heavy metal atoms.

15. An integrated workpiece processing apparatus comprising:
 - a) a first vacuum processing chamber adapted to plasma clean a workpiece with a plasma having a high ion density, low ion energy and low plasma potential, said first processing chamber fitted with a first workpiece support;
 - b) a second vacuum processing chamber adapted to perform a semiconductor fabrication process, said second processing chamber being fitted with a second workpiece support; and
 - c) a vacuum transfer chamber connecting said first and second chambers and through which a workpiece may pass.
16. An apparatus according to claim 15, wherein the semiconductor fabrication process performed in said second vacuum processing chamber is selected from the group consisting of CVD, PVD, sputtering and etching of a workpiece.
17. An apparatus according to claim 15, wherein said first vacuum processing chamber is an ESRF plasma reactor.
- 20 18. An apparatus according to claim 17, further comprising:
 - d) a workpiece handling and robotics system for transferring a workpiece to and from said first workpiece support and to and from said second workpiece support; and
 - e) a gas supply system for supplying a gas containing hydrogen to said first vacuum processing chamber; and
 - f) a vacuum system pneumatically connected to said first vacuum processing system.
- 25 30 19. An apparatus according to claim 18, further including a control system electronically connected to said workpiece handling and robotics system, to said gas supply system, and to said vacuum system, for controlling the operation of the apparatus.

1/2

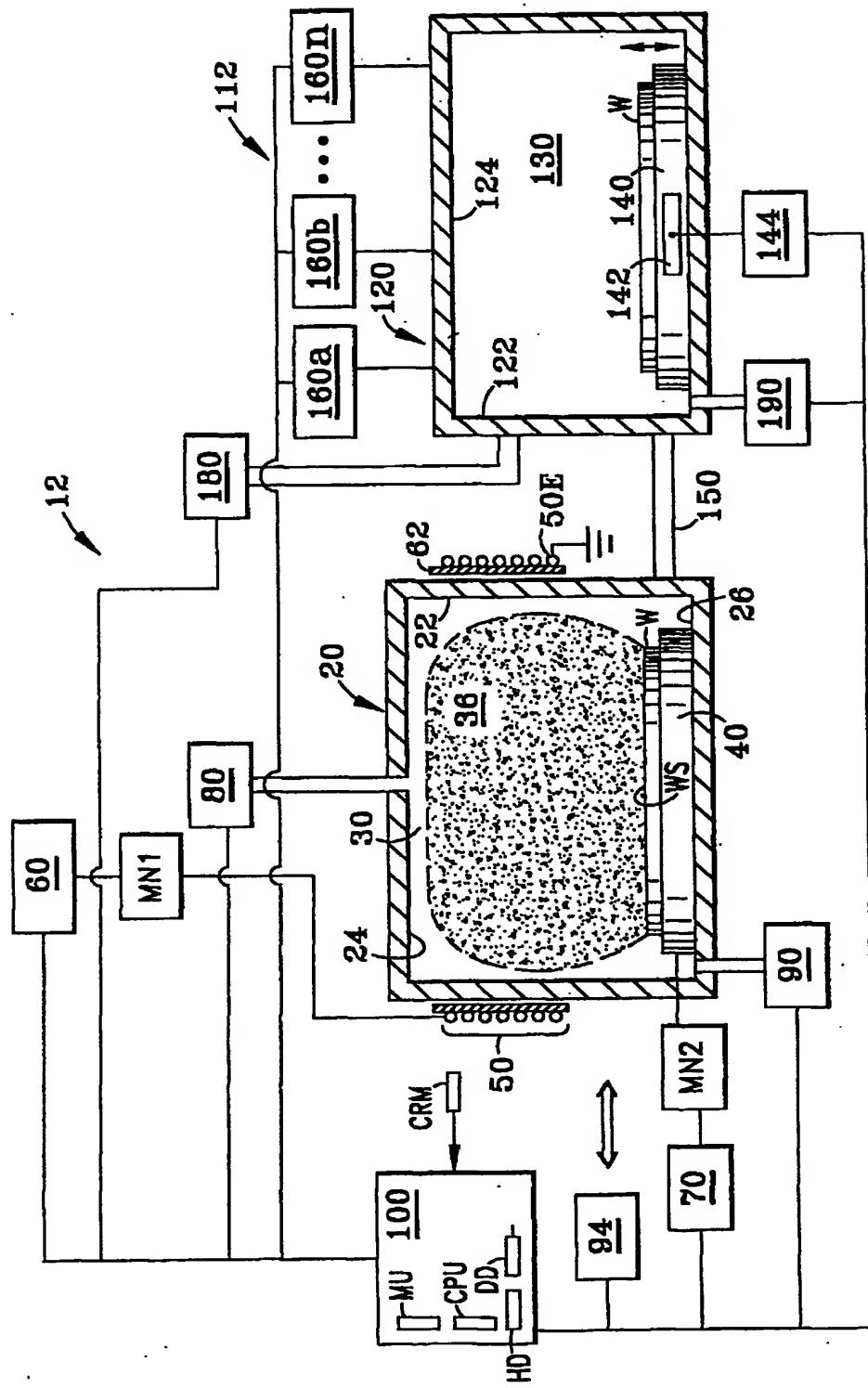


FIG. 1

2/2

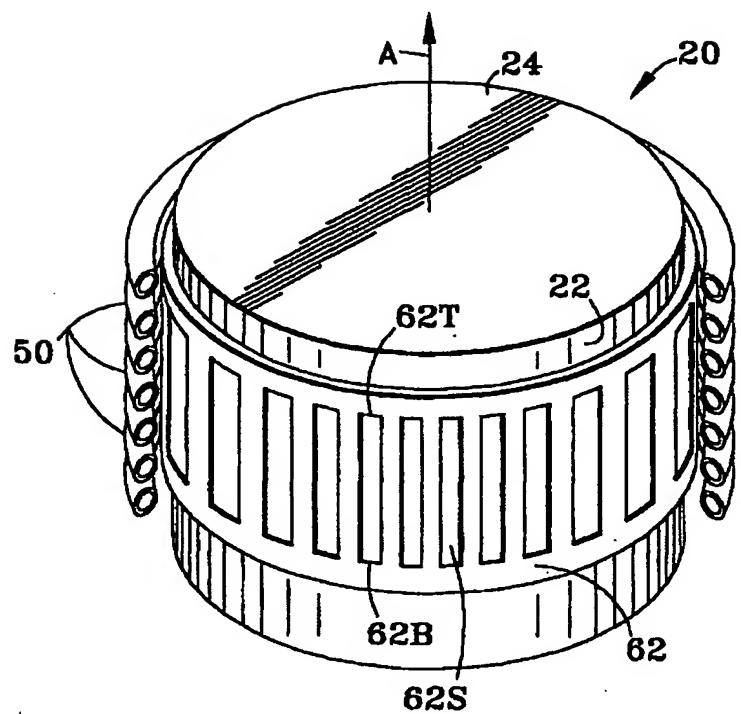


FIG. 2

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
1 November 2001 (01.11.2001)

PCT

(10) International Publication Number
WO 01/82355 A3

(51) International Patent Classification⁷: **H01L 21/306.** (74) Agents: **LAZAR, Dale, S. et al.; Pillsbury Winthrop LLP, 1600 Tysons Boulevard McLean, Virginia 22102 (US).**

(21) International Application Number: **PCT/US01/13002**

(81) Designated States (*national*): **AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.**

(22) International Filing Date: **23 April 2001 (23.04.2001)**

(84) Designated States (*regional*): **ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).**

(25) Filing Language: **English**

Published:

(26) Publication Language: **English**

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(30) Priority Data:
60/199,354 25 April 2000 (25.04.2000) US

[Continued on next page]

(71) Applicant (*for all designated States except US*): **TOKYO ELECTRON LIMITED [JP/JP]; TBS Broadcast Center, 3-6 Akasaka 5-chome, Minato-ku, Tokyo 107 (JP).**

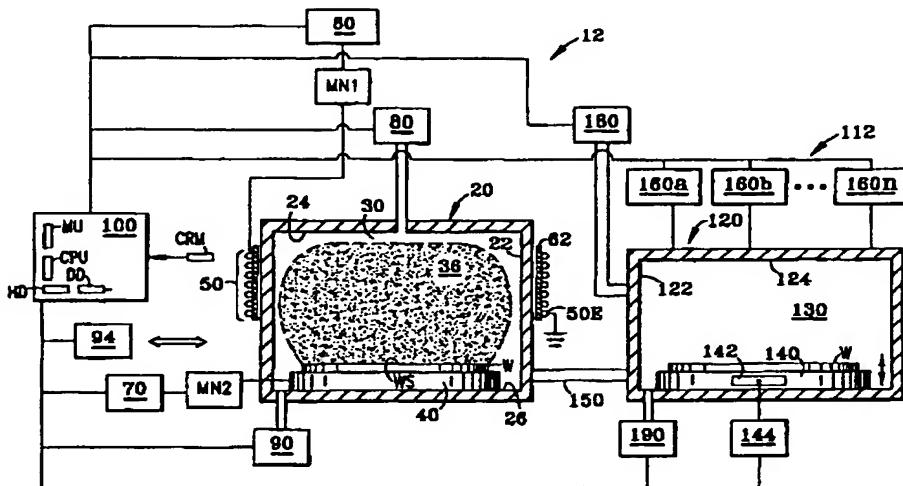
(72) Inventor; and

(75) Inventor/Applicant (*for US only*): **LIU, Lianjun [US/US]; 100 W. Napal Place #232, Chandler, AZ 85224 (US).**

(54) Title: **METHOD AND APPARATUS FOR PLASMA CLEANING OF WORKPIECES**



WO 01/82355 A3



(57) Abstract: A method and apparatus for plasma cleaning a workpiece (W) in a plasma-cleaning chamber (20) having an interior region (30). The method comprises the steps of first, loading the workpiece into the plasma-cleaning chamber interior region. The next step is pumping down the plasma-cleaning chamber interior region down to a pre-determined pressure, with hydrogen as the ambient gas. The next step is forming from the hydrogen gas a plasma (36) having an ion density in the range between 10^{10} and 10^{13} cm^{-3} and an ion energy lower than 30 eV. The last step is exposing the workpiece to the plasma for a predetermined time. The apparatus of the present invention preferably includes first and second vacuum processing chambers (20 and 120), wherein the first chamber performs the plasma cleaning of the workpiece according to the method of the invention, and the second chamber performs an additional process step, e.g., depositing a metal.



(88) Date of publication of the international search report:
21 March 2002

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 01/13002

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 7 H01L21/306 H01L21/285 H01L21/00 H01J37/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 IPC 7 H01L H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99 34424 A (APPLIED MATERIALS) 8 July 1999 (1999-07-08) page 14, paragraph 3; figures 2,5	15-19
Y	---	1-14
Y	AOKI Y: "IN SITU SUBSTRATE SURFACE CLEANING BY LOW-ENERGY ION BOMBARDMENT FOR HIGH QUALITY THIN FILM FORMATION" JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART A, AMERICAN INSTITUTE OF PHYSICS. NEW YORK, US, vol. 11, no. 2, 1 March 1993 (1993-03-01), pages 307-313, XP000364354 ISSN: 0734-2101 the whole document ---	1-14

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *&* document member of the same patent family

Date of the actual completion of the international search

8 January 2002

Date of mailing of the international search report

15/01/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040, Tx. 31 651 epo nl.
 Fax: (+31-70) 340-3016

Authorized officer

Gori, P

1

Form PCT/ISA/210 (second sheet) (July 1992)

page 1 of 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/13002

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 915 204 A (SUMI) 22 June 1999 (1999-06-22) column 5, line 5 - line 20; claims ---	1-14
A	GROTHJORN T A: "ION SOURCES FOR MICROFABRICATION (INVITED)" REVIEW OF SCIENTIFIC INSTRUMENTS, AMERICAN INSTITUTE OF PHYSICS. NEW YORK, US, vol. 65, no. 4, PART 2, 1 April 1994 (1994-04-01), pages 1298-1303, XP000453928 ISSN: 0034-6748 page 1301, right-hand column, paragraph B ---	1-14
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 06, 22 September 2000 (2000-09-22) -& JP 2000 082681 A (SONY CORP), 21 March 2000 (2000-03-21) abstract ---	1-14
P,X	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 08, 6 October 2000 (2000-10-06) -& JP 2000 150479 A (CANON INC), 30 May 2000 (2000-05-30) abstract -----	1-14

FURTHER INFORMATION CONTINUED FROM PCT/USA/ 210

Continuation of Box I.2

The term "ESRF" in claim 17 has not been defined. Consequently it cannot be determined which features this term should comprise.

For the search the term "ESRF" has been replaced by "inductively coupled". The search is thus not complete for said claim 17.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/13002

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO 9934424	A 08-07-1999	US 6107192 A	EP 1042795 A1	22-08-2000
		TW 411497 B		11-10-2000
		WO 9934424 A1		11-11-2000
				08-07-1999
US 5915204	A 22-06-1999	JP 8264483 A		11-10-1996
JP 2000082681	A 21-03-2000	NONE		
JP 2000150479	A 30-05-2000	NONE		

Form PCT/ISA/210 (patent family annex) (July 1992)

BNSDOCID: <WO_0182355A3_1>

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record.**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- BLACK BORDERS**
- IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- FADED TEXT OR DRAWING**
- BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- SKEWED/SLANTED IMAGES**
- COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- GRAY SCALE DOCUMENTS**
- LINES OR MARKS ON ORIGINAL DOCUMENT**
- REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.